Atmospheric ν in MINOS

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RAL

Atmospheric neutrinos are interacting in MINOS now. Physics before the beam.

- What can we do?
- How can we do it?
- How can we get organised?

Parallel session featured talks by

- PJL on interactions in the detector
- Jim Musser on upward muons
- Alec Habig on lessons from Super-K
- Bernard Becker on CPT

What can we do?

- MINOS is smaller than Super-K and MACRO, we cannot match their statistics but we have the magnetic field. We should make maximum use of it.
  - Separate μ^+ μ^-, ν $\bar{\nu}$
  - Measure momentum of uncontained μ
  - Measure μ direction by slowing in the field
- Physics
  - Conventional oscillation analysis of contained and partially contained events
  - Upward muons from rock interactions
  - WIMPs
  - Search for CPT violation

Contained events

- MC analyses by David Petyt and PJL written up in a NuMI note
  - High energy (>1Gev) muon events easiest to separate and most sensitive to oscillations.
  - ~400 events remaining from an 18 kton-year exposure (~4 year run)
  - Magnetic field used to measure energy of exiting muons and help define event direction
  - Separation of ν and anti-ν enables check of flux calculations and/or a check of CPT (Bernard Becker's talk). By CPT $\nu_\mu \rightarrow \nu_\mu$ and $\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu$ must be equal.

What should we be doing?

•Most important job is tuning the reconstruction programs to the level at which a filter can begin to find some event candidates at a reasonable level (1 in 1000 failures on cosmic muons?). Very strong overlap with the reconstruction group.

•Upward muons are easiest to extract, the timing gives an extra handle. If you want a thesis soon this is your subject…

•Atmospheric neutrino, upward stop and cosmic muon GMINOS files existed. Probably now unreadable and/or unconvertible to the framework. Hugh Gallagher has promised to include the neutrino and muon generators into NEUGEN, probably the quickest route to new MC. All the MC work needs redoing with up to date detector conditions and reconstruction.

•Stan is proposing setting up working groups on atmospheric neutrinos and cosmic muons. If you are interested contact the conveners, particularly if you want to do some work on the reconstruction/filter.

How do we find them?

•~100 visible atmospheric neutrino interactions /kton/year before any cuts, ~1.5/day in MINOS.

•~1Hz of cosmic ray muons, 86400/day, no time cut as for beam events. Need to reject cosmic muons at 10^6:1

•Cosmic muons interact in the detector, mostly electromagnetically producing electron showers but some hadronically.

•Extremely efficient reconstruction program required which reconstructs cosmic muons and checks for entry and exit of the muon (and direction)

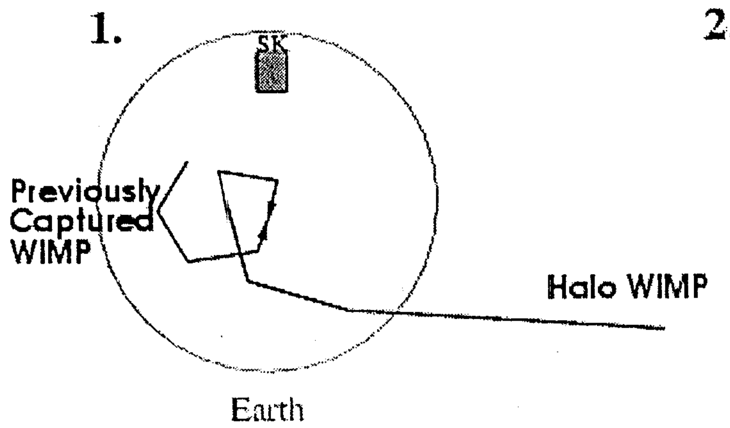
•Problems with vertical muons which cross few, if any, planes. Probably need cuts on event direction and/or planes crossed. Bad for up/down assymetry

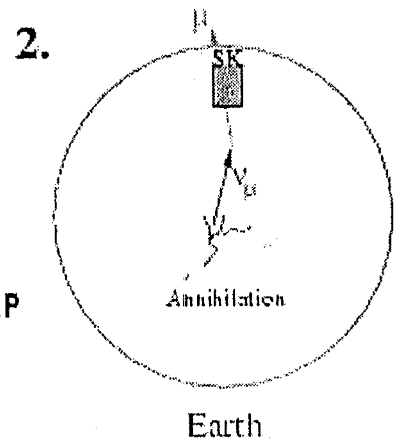
•Problems with demultiplexing

•Worse problems with partially contained events, only one end is contained

•Soudan 2 had a shield which flagged ~95% of through going muons. A shield for MINOS?

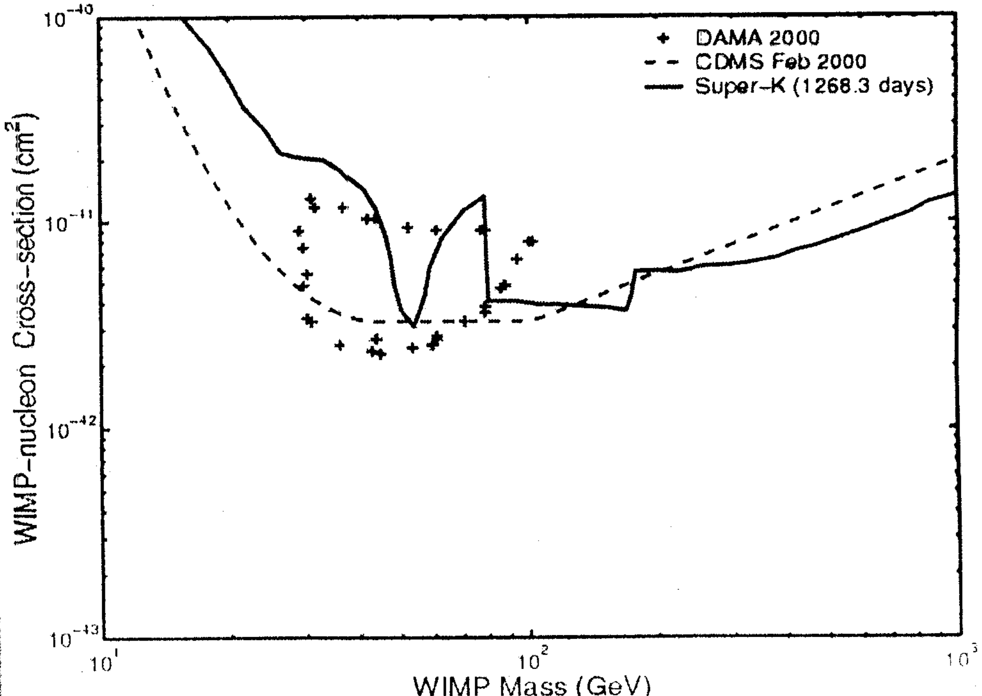
WIMP Results





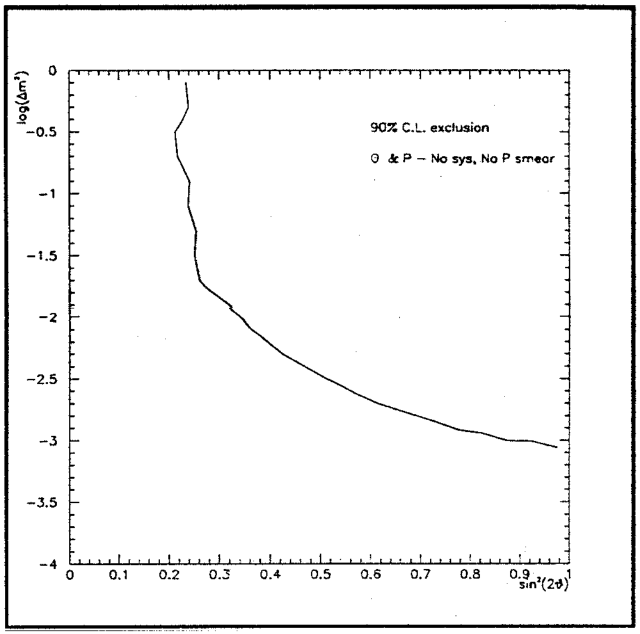
WIMPs capture, Annhilate, make νs and up-μs

SK WIMP limits, compared to DAMA & CDMS

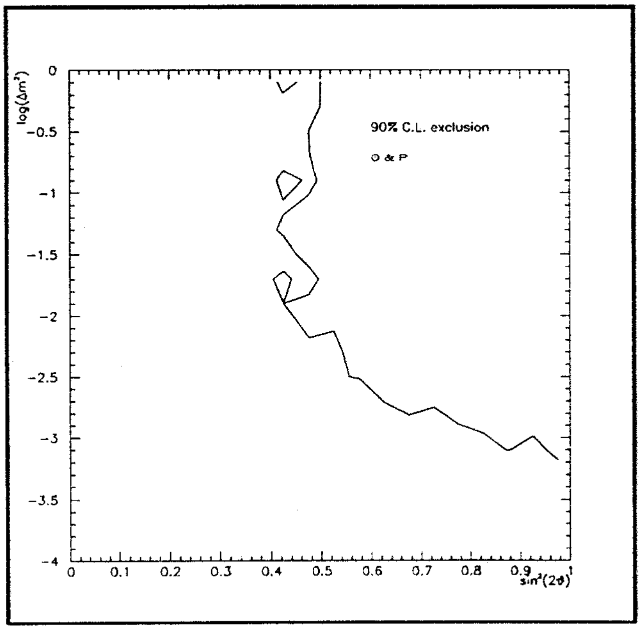


Results

90% exclusion plot for no systematic error, no momentum smearing



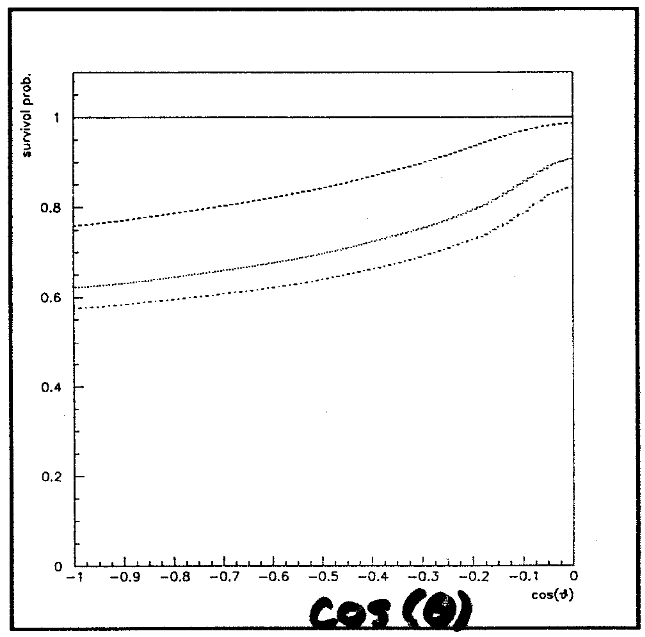
90% exclusion plot with systematic error, momentum smearing.



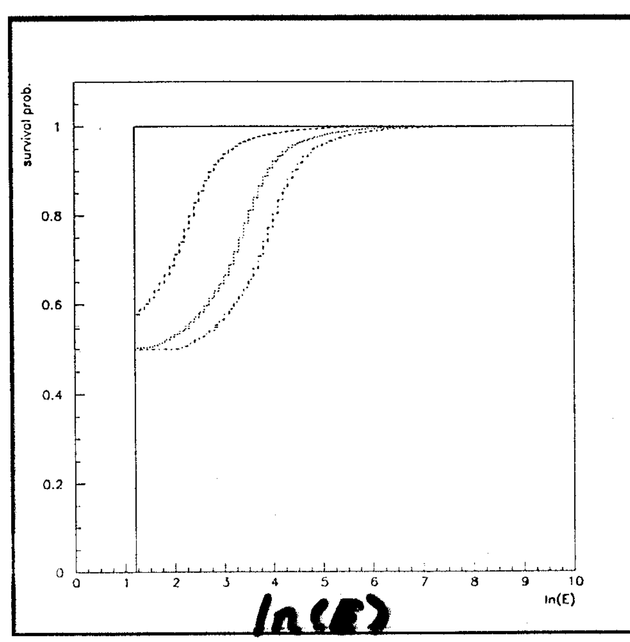
Survival Prob. Vs Zenith Angle and Muon Energy

For maximal mixing, plots below show survival prob. vs θ_z and ln(E) for Δm^2=0, 0.001, 0.005, and 0.01 eV^2.

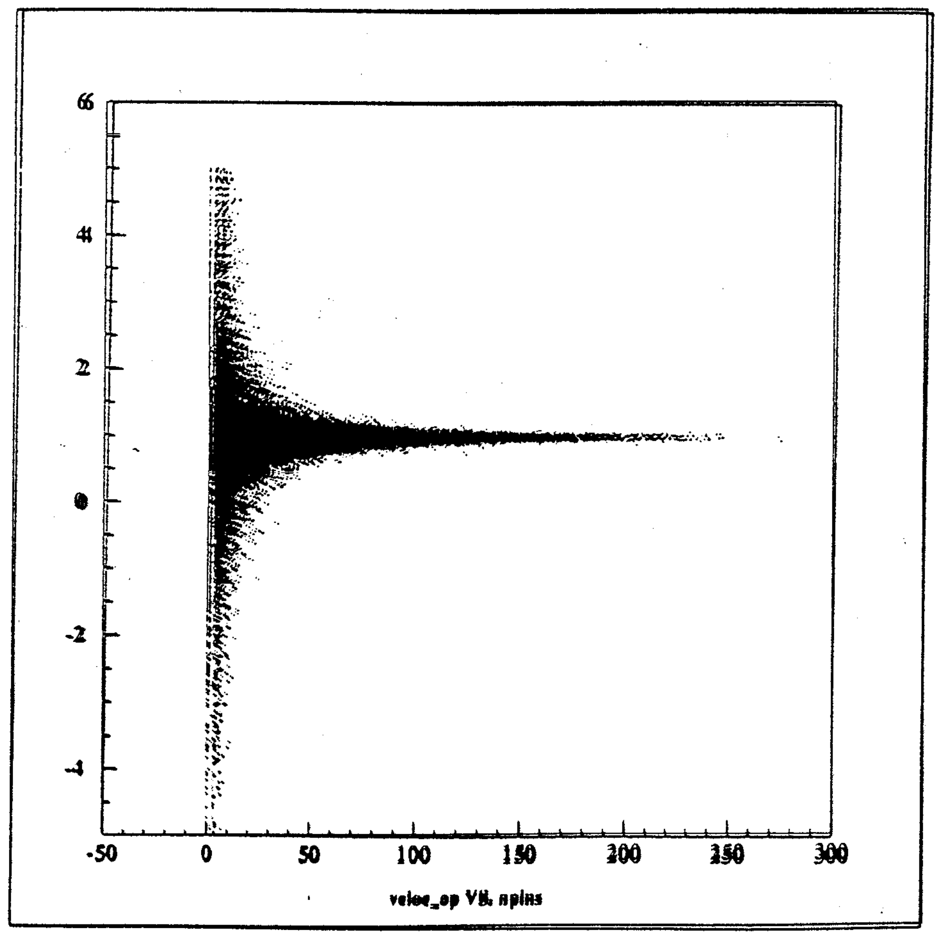
Survival Prob. Vs Zenith Angle



Survival Prob. Vs ln(E)

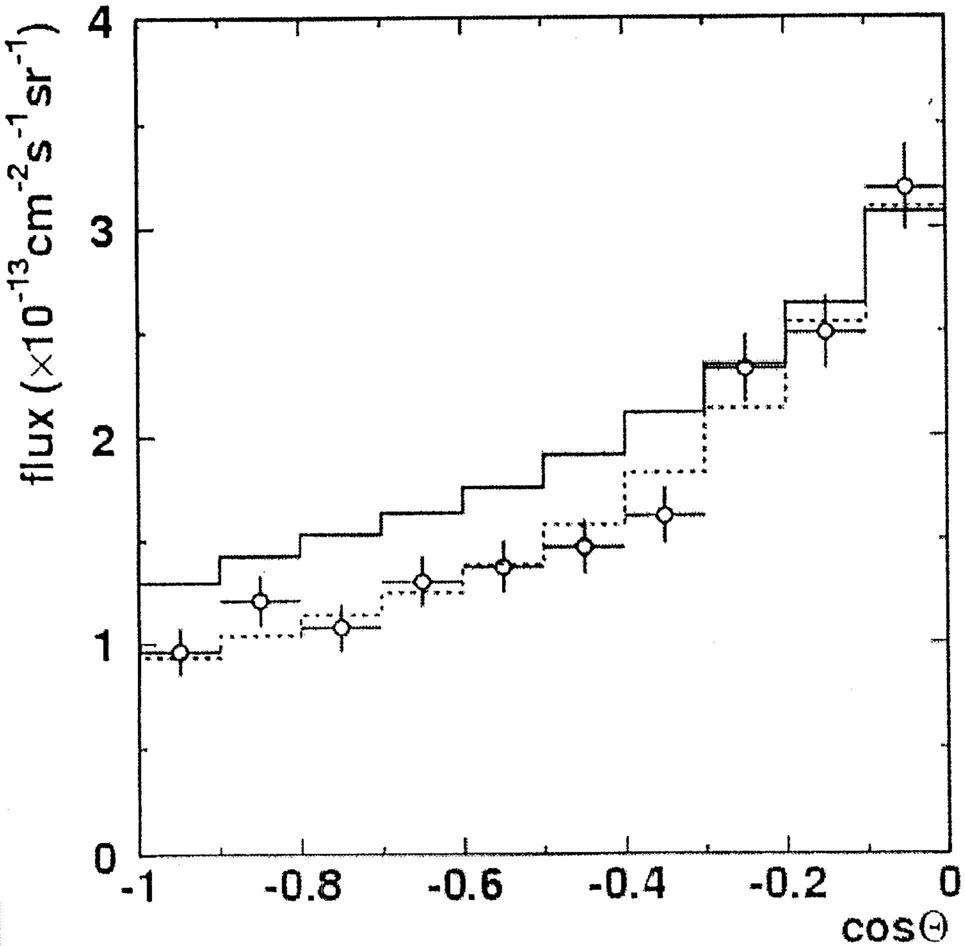


$1/\beta$ vs track length



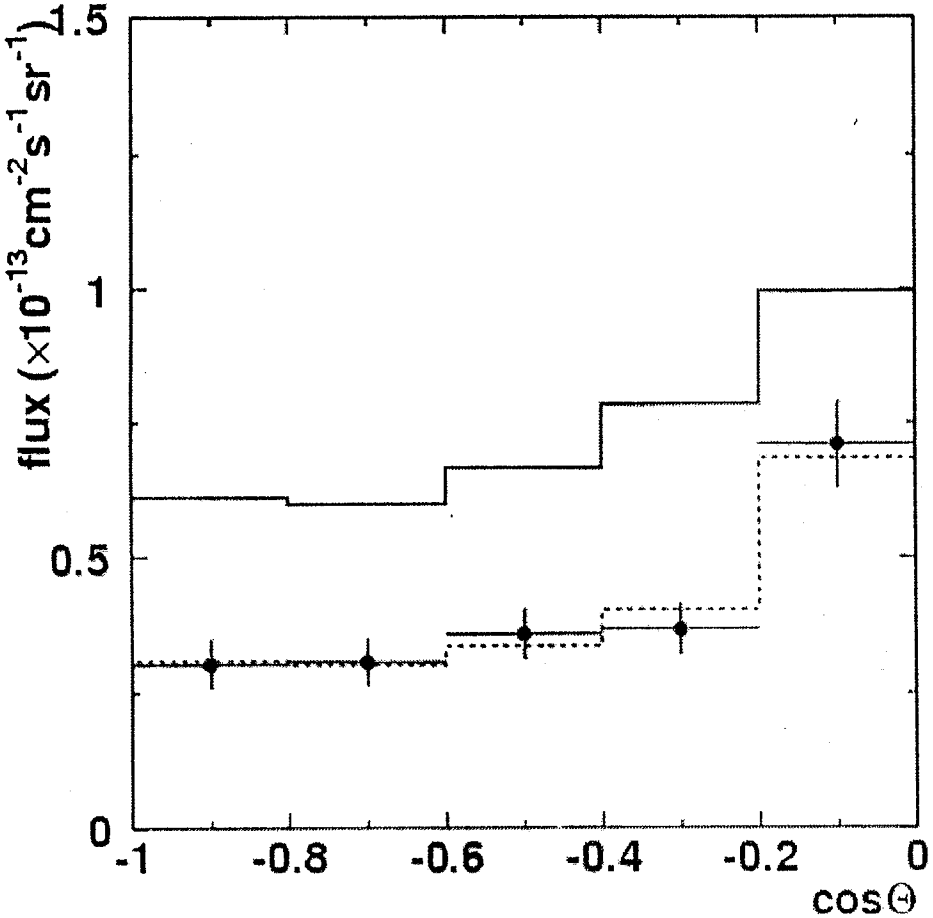
cut @ 20-30 planes needed

Up-Through μ flux



- Data - crosses
- Black - no-osc
- Red – ν_μ✡ν_τ osc, Δm^2=3.2x10^{-3} eV^2, $\sin^2 2\theta$=1.0
- Note shape distortion due to osc
- High through-μ statistics sets overall flux normalization

Up-stop μ flux



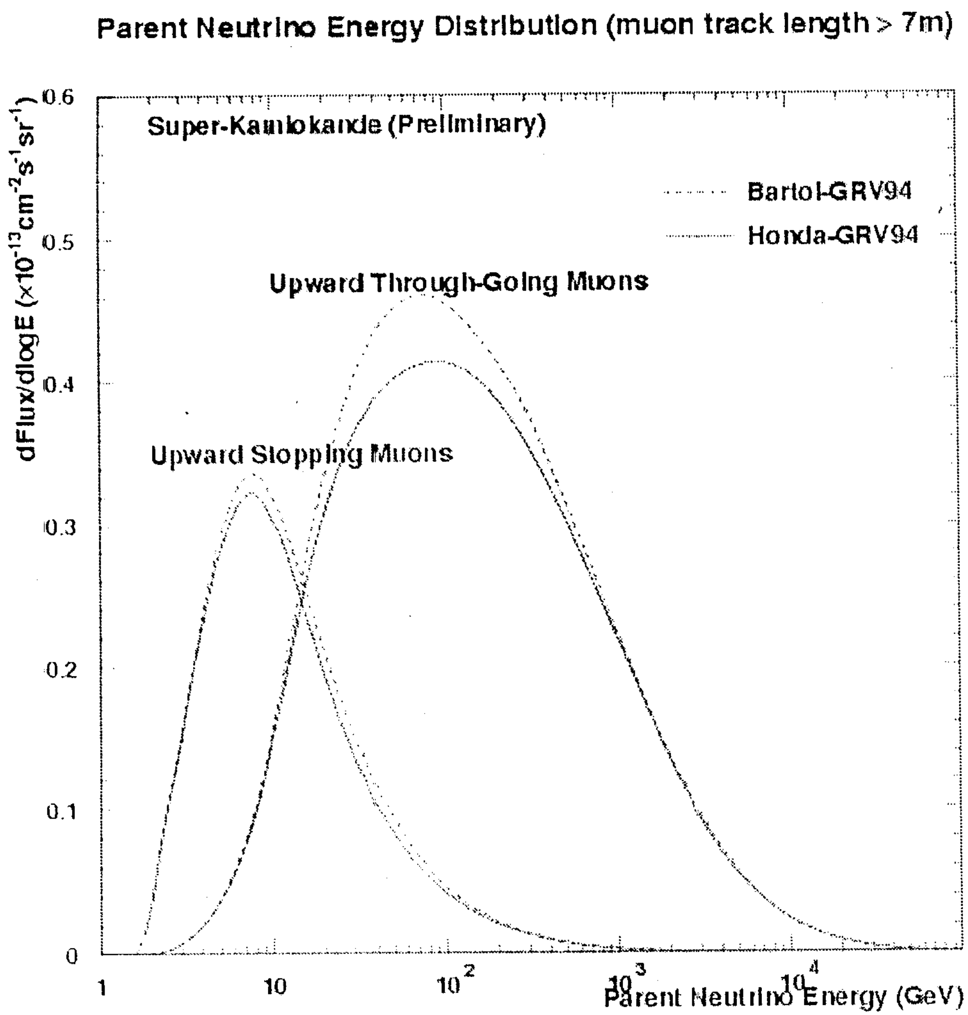
- Data - crosses
- Black - no-osc
- Red - ν_μ✡ν_τ osc, $\Delta m^2=3.2\times10^{-3}$ eV^2, $\sin^2 2\theta=1.0$
- Stop-μ strongly oscillated
- Without Through-μ to set normalization, this suppression is within theory error

Upward muons

Jim Musser, analysis written up as NuMI note(?)

- Gives access to high energy ν which interact in the rock below the detector and produce a muon which passes through or stops in the detector
- Muon energy not too well correlated with neutrino energy but the magnetic field enables division into at least 3 samples
  1. Low energy, stops
  2. Medium energy, momentum measured by curvature in the field
  3. High energy, no measurable curvature
- Charge separation gives a check on flux calculations at high energy and/or possible physics surprises
- Field helps in the separation of upward stopping muons from downward semi-contained neutrino interactions

Parent ν Energy

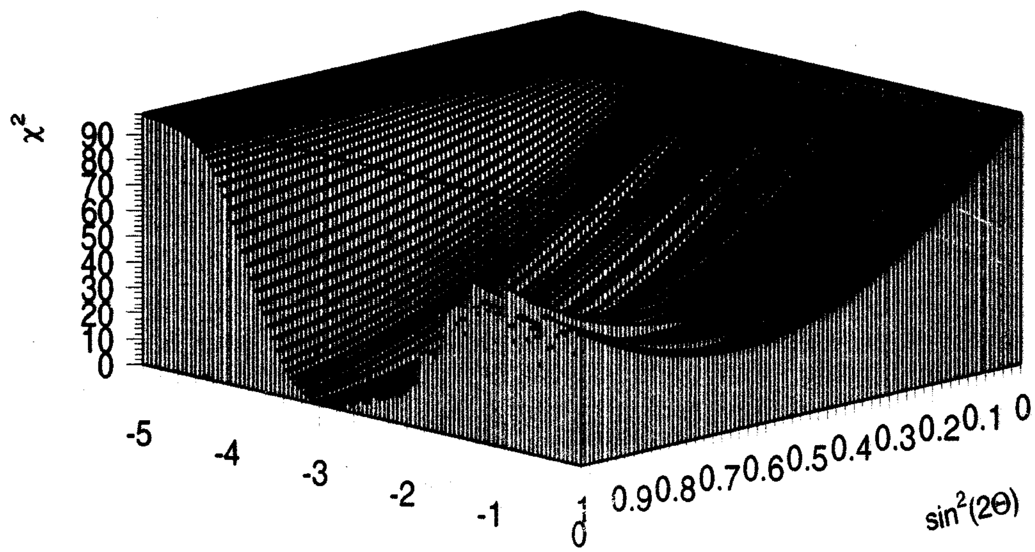


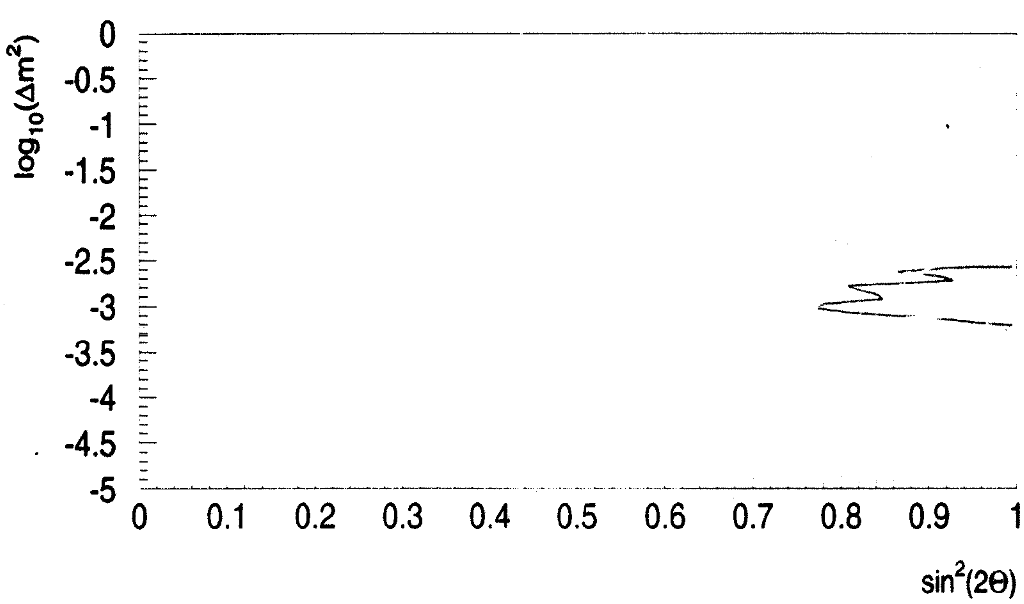
- Through-going μ from ~100 GeV ν
- Stopping-μ from ~10 GeV ν
- Pathlength cuts provide little additional discrimination

Parameter measurement sensitivity

$\Delta m^2 = 10^{-3}$,$\sin^2(2\theta) = 1.0$

Fixed normalisation





$\Delta m^2 = 10^{-3}$ $\sin^2 2\Theta = 1.0$